SAB "QUICK LOOK" STUDY OF HOLLOMAN HIGH SPEED TEST TRACK (HHSTT) UPGRADE OPTIONS

Final Report

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Outline of Report

- Study Terms of Reference
- Team Composition
- High Speed Test Track Applications
- Maglev
  - Background
  - Findings
- Conventional Upgrade
  - Background
  - Findings
- Alternate Paradigms
- Recommendations

SAB “QUICK LOOK” STUDY OF HOLLOMAN HIGH SPEED TEST TRACK (HHSTT)

Study Purposes

- Investigate current state of the art of Maglev technology and its potential for *affordable* application to hypersonic sled track testing
- Investigate “conventional upgrade” capability for hypersonic sled track testing addressing risk of vibration environments and new rocket motor development

SAB "QUICK LOOK" STUDY OF HOLLOMAN HIGH SPEED TEST TRACK (HHSTT)

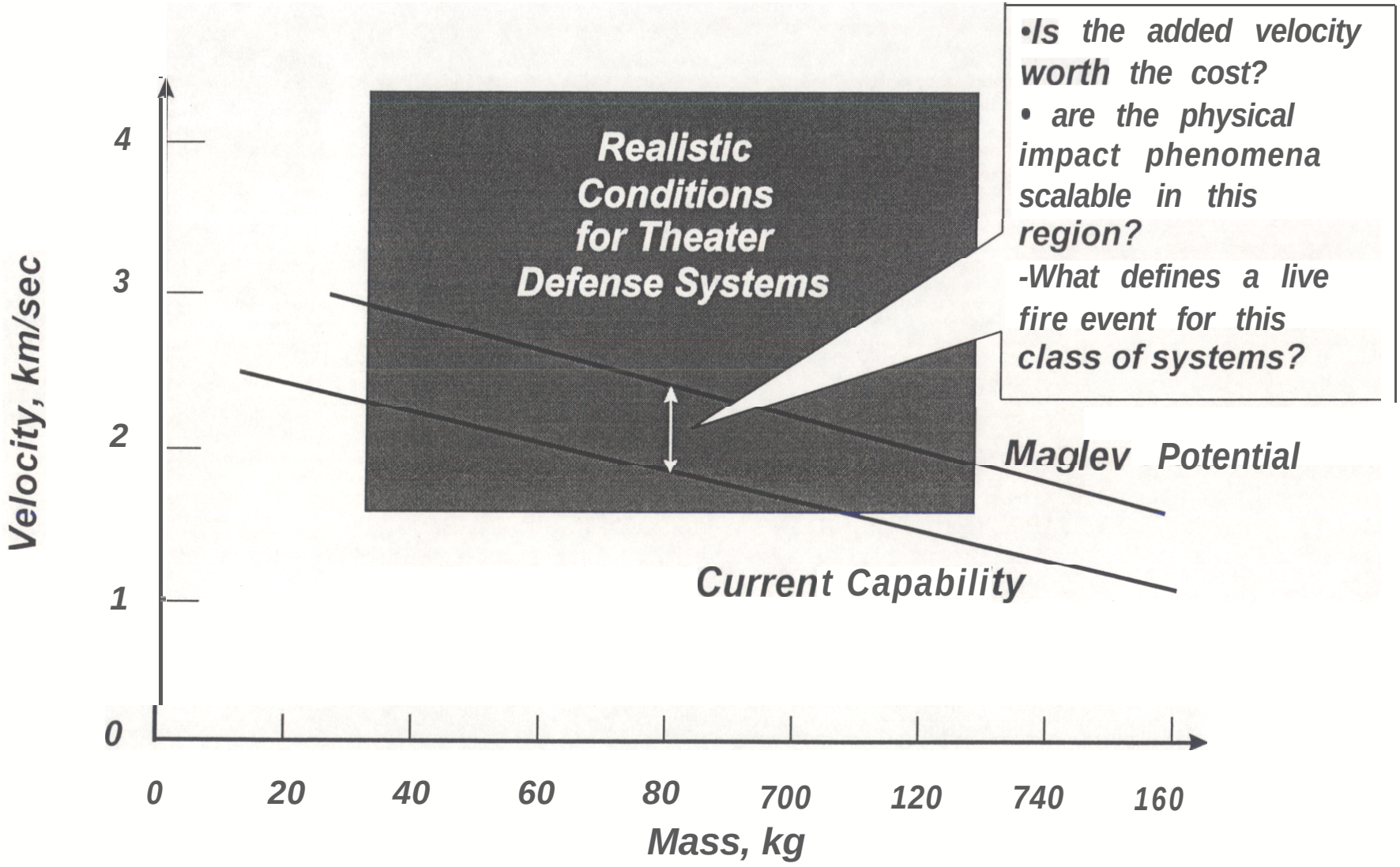
Team

- Dr. Alan C. Eckbreth, UTRC - Chair
- Prof. A.F. "Skip" Grandt, Purdue
- Dr. Edward Kraft, Microcraft
- Dr. James Lang, Boeing
- Dr. John P. McCarty, McCarty Group
- Capt. Joel Schubbe, AFRL/VASS
- Dr. Robert Selden, LASL (ret)
- Mr. Ralph Shimovetz, AFRL/VASS
- Prof. Richard D. Thornton, MIT and MagneMotion
- Prof. Rick I. Zadoks, UTEP
- Prof. Ben T. Zinn, Georgia Tech
- Maj. Victor Monti, AF/SAB, Executive Officer

Hypersonic Impact TMD Lethality Testing - Performance Requirements

- Impact velocities in the -2-5 km/sec range
- Realistic payloads up to 100 kgm
- Accelerations not to exceed 250 g's
- Total post impact target recovery
- Precise control of impact geometry - within 5 deg and 12.7cm (5") of desired impact

Fundamentalissues for TMD Testing



Holloman High Speed Test Track

Applications - Existing and Potential

- Lethality testing
  - Current Theatre Missile Defense Programs; upgrade too late for several MDAP programs; could impact THAAD, SM-3 LFT&E
  - Future TMD Programs
  - National Missile Defense - 6 to 13 km/sec req'd
- Hypersonic propulsion testing
  - controlled ground testing of ram/scramjets
  - will require partial evacuation of test section

SAB "QUICK LOOK" STUDY OF HOLLOMAN HIGH SPEED TEST TRACK (HHSTT) - Maglev Approach

Study Purpose:

- Investigate current state of the art of maglev technology and its potential for *affordable* application to hypersonic sled track testing

Conclusions:

- Maglev technology is not sufficiently mature at this time for application in this challenging environment
- Significant development efforts will be required, including new design approaches/paradigms, for successful and affordable application to hypersonic sled track testing

Maglev Suspension/Propulsion

Benefits for Sled Track Testing

- Very low vibrational g levels preclude need to harden payloads
- Eliminates the traditional rail/slipper interface problem and lifing issues
- Potential for very high speed with electro-magnetic propulsion or upgraded rocket motors

Technical Challenges of Maglev

- Damping of sled vehicle oscillations
- Superconducting magnet design
- Quenching
- Costs for infrastructure and test vehicles

Damping of Sled Oscillations

- Maglev suspension systems are highly underdamped
- No simple solution to providing damping
- Situation is similar in both heave (up/down) and sway (side/side)
- Initial design 1mm thick Al plates for damping not particularly effective due to large skin depth
- Aerodynamic control ruled out (?); active magnetic current control not considered

Superconducting Magnet Design and Quenching

- Extremely difficult design problem due to size, weight and cost constraints
- Necessitated use of NbTi wire at liquid He boiling point, 4.2K @ I atm
- The magnetic field must not exceed 6-8 Tesla to prevent quenching
- Quenching will occur @ ~ 550 kA-turns
- Wing coils designed to 500 k&turns to produce 1.8 Tesla in guideway

Superconducting Magnet Design and Quenching -- cont'd

- Operating current is -90% of quench condition
- Sway motion can induce large AC currents in wing coils causing quenching
- Skin depth of Al at 5 to 20 Hz is 8mm; tested shields were lmm thick, thus ineffective

Costs for Infrastructure a Design Vehicles

- Low drag, lightweight, cryogenic (~4K) sup magnet design is challenging requiring sophi design and a concomitantly high cost
- Racetrack coil shape can lead to large mecha in superconducting wire leading to manufact challenges
- High for sled since superconducting magnets with each test in current paradigm
- Large infrastructure costs associated with nev and cryogenic facilities

Maglev Suspension
Findings

- Hypersonic test track application of maglev technology is very challenging
- Present design is very aggressive for superconducting magnets
- Per test cost very high and driven by loss of wing coil magnets with sled in current end game scenario

  Wing coils are very expensive driven by size/shape constraints and thermal jacketing requirements
- Current design is highly underdamped and stability will be problematical
- Quenching is likely to be a persistent problem with the present design

Maglev Suspension for HHSST Conclusions

- Maglev technology is not sufficiently mature at this time for application in this challenging environment
- Significant development efforts will be required, including new design approaches/paradigms, for successful and affordable application to hypersonic sled track testing

SAB “QUICK LOOK” STUDY OF HOLLOMAN HIGH SPEED TEST TRACK (HHSTT) - Conventional Upgrade

Study Purpose:

- Investigate “conventional upgrade” capability for hypersonic sled track testing addressing risk of vibration environments and new rocket motor development
- Conclusion:
- Conventional upgrade approach appears to be of medium risk with no show stoppers evident

Conventional Approach Up

Technical Challenges

- Slipper-rail interactions
  - rail gouging
  - slipper life
  - alignment
- Rocket motor
  - vibration environment

SAB "QUICK LOOK" STUDY OF HOLLOMAN HIGH SPEED TEST TRACK (HHSTT) - Conventional Upgrade

Conclusion

- Conventional upgrade approach appears to be of medium risk with no show stoppers evident

Technical Challenges of High Speed Test Track Testing

Common issues independent of propulsion and suspension systems

- Pulldown
- Low density atmosphere
- System integration
- Maintenance

Common Technical Challenges Findings

- Pulldown leads to high per unit test costs due to the destruction of the sled. Pulldown rail maintenance costs will likely increase at higher speeds.
- The marginal gain in using H2 instead of He for the low density atmosphere does not appear attractive enough to offset H2 handling infrastructure costs and increased safety requirements
- Out of the box systems approaches might reduce the technical challenges and risks of high speed test track operation
- A dedicated maintenance program will be required to maintain HHSTT as a world class facility and national asset

Alternate Paradigms - Free Flyer

Make the last one or two stages a powered free flyer

- Minimizes slipper wear and aero heating on sled since sled doesn't reach max velocity
- Avoids technical difficulties and cost of pull down
- Low cost guidance systems available
- Recovers sleds
- May eliminate bagging for drag reduction since entire sled not accelerated to final speed
- Technical challenges
  - Accuracy in target interaction
  - Design of the free flyer
  - Range safety

Alternate Paradigms - Counterfire

Employ a counter-fire approach that launches the test article and target at each other

- Essentially doubles impact velocity using current technology and state-of-the-art
- Technical challenges
  - Timing events, particularly timing ignition of solid rocket motors
  - Cost of additional track
  - Avoidance of sled debris in impact area
  - Accuracy of impact event

Quick Look Study of HH

Recommendations

- Proceed with the conventional hypersonic to the HHSTT
  - Test new rocket motors under vibration/force conditions that dynamically simulate actual t
  - Invest in rail upgrades, rail alignment capabi improved rail/slipper designs based on detai modeling analyses and appropriate verificati
  - Develop enhanced modeling and analysis sk HHSTT via collaborative partnerships
  - Consider deployment of secondary suspensi systems to contain vibrations to an acceptabl including active control
  - Perform a detailed assessment of the total tes and cost impacts of a H2 atmosphere before

Quick Look Study of HHSTT

Recommendations -- cont'd

- Pursue a maglev technology development program to prepare for future national requirements
  - Invest first in study projects with potential to lead to major improvements in test capability in next 3 to 10 years
  - Develop technology in subscale experiments mindful of scaling issues
  - Phase these maglev development efforts consistent with capability requirements of national programs
  - Encourage DARPA to support research on maglev and linear propulsion for dual use applications, e.g., test tracks and transportation systems

Quick Look Study of HHSTT

Recommendations -- cont'd

- Consider alternate paradigms to high speed test track testing such as hybrid approaches with guided, powered free flying final stages; counterfire; aerodynamic control; alternative rail configurations; hydrodynamic bearings; evacuated tubes
- Define and implement a plan for future sustainment and development of HHSTT

APPENDIX

Biographical Sketches of HHSTT Study Panel Members

Dr. Alan C. Eckbreth
Director. Pratt & Whitney Programs
United Technologies Research Center
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Alan C. Eckbreth received a Bachelor of Science degree in Engineering Physics (summa cum laude) from Lehigh University in June 1964. At Lehigh, he performed undergraduate honors research and was a member of Tau Beta Pi, Sigma Xi and Phi Beta Kappa. He received his doctorate in Aerospace and Mechanical Sciences from Princeton University in the fall of 1968. His thesis research, directed by Prof. Robert G. Jahn, involved investigations of current pattern and gas flow stabilization in pulsed plasma accelerators. In 1976, he was awarded an M.S. in Administrative Sciences from Rensselaer Polytechnic Institute. In August 1968, he joined the then United Aircraft Research Laboratories as a Senior Research Scientist. From 1968 to 1973, he engaged in experimental and analytical research into the optical and plasma properties of electric-discharge CO2 convection lasers. Since 1973 he has conducted analytical and experimental investigations of laser Raman scattering, laser-induced fluorescence and coherent anti-Stokes Raman spectroscopy (CARS) for gas dynamic and combustion diagnostic purposes. Beginning in 1986. he has served in a number of increasingly responsible senior management positions. Currently, as Director, Pratt & Whitney Programs, he is responsible for providing strategic direction and leading the formulation and execution of the co-planned $40M/yr Pratt & Whitney technology program at UTRC across all areas of design, materials and manufacturing technologies. He serves as the primary technology and business contact between the Research Center and P&W. In addition, he is responsible for external resourcing campaigns, bid and proposal funding. capital budgeting and intellectual property strategies. He is the author of over sixty technical papers and the book Laser Diagnostics for Combustion Temperature and Species published as a fully revised, second edition in July of 1996. He has lectured in courses at the Israel Institute of Technology, Purdue University, University of Connecticut, Exxon, Instituto Superior Tecnico. and Sandia National Laboratories, and has given numerous seminars. He holds six patents and is a member of the U.S. Air Force Scientific Advisory Board, the Combustion Institute, American Society of Mechanical Engineers and the Connecticut Academy of Science and Engineering. He is a Fellow of both the American Institute of Aeronautics and Astronautics and the Optical Society of America. In 1985, he received the George Mead Medal from United Technologies Corporation for outstanding engineering achievement.

Professor Alten F. (Skip) Grandt, Jr.
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A. F. Grandt, Jr. received his Ph.D. in theoretical and applied mechanics at the University of Illinois in 1971, and was then employed by the Air Force Materials Laboratory from 1971-79. That position focused on basic research directed toward implementing the new USAF damage tolerance analysis approach for airframe and engine design developed and adopted during the 1970's. He joined the Purdue School of Aeronautics and Astronautics in 1979, and served as Head of the School from 1985 through 1992. His research interests deal with fundamental problems associated with predicting the fatigue and fracture behavior of aerospace structures, and includes recent emphasis on aging aircraft issues. He has served as principal investigator for over $5 million in externally sponsored research at Purdue. has published over 120 technical papers dealing with fatigue and fracture, and has advised over 45 graduate theses in those areas. He teaches undergraduate and graduate courses dealing with structural analysis, design, fatigue, and nondestructive inspection, and has offered short courses on damage tolerance analysis methods to over 750 practicing engineers from government and industry. He is a Fellow of the American Institute of Aeronautics and Astronautics.

Dr. Edward M. Kraft
Micro Craft, Inc.

Dr. Edward M. Kraft is Executive Vice President for Operations at Micro Craft, Inc. in Tullahoma, Tennessee, a woman-owned small business dedicated to providing full spectrum support to research, development, test and evaluation. He is responsible for strategic planning, marketing and overall operations of the company whose products and services include engineering analysis, design, manufacture of prototype hardware, instrumentation. calibration, test support, testing, test analysis, operations and maintenance of test facilities, and manufacture of flight hardware.

Dr. Kraft has over 28 years experience at the U.S. Air Force Arnold Engineering Development Center, where he held a number of technical and management positions. including General Manager of the Micro Craft Technology operating contract for all flight dynamic test facilities. His experience includes wind tunnel test engineering. test technology development, test facility research and development, flow diagnostic development, and the application of computer simulations to T&E. He has been the principal proponent for the integrated T&E process, which melds modeling and simulation with ground testing and flight testing to reduce the time and cost of system development. Application of this integrated T&E approach resulted in major savings to programs like the F-15E and F-22.

A recipient of numerous awards, Dr. Kraft is a Fellow of the American Institute of Aeronautics and Astronautics, a Fellow of the Arnold Engineering Development Center. and a Distinguished Alumnus of the University of Tennessee Space Institute. He is an adjunct professor of aerospace engineering at the University of Tennessee Space Institute. He is also a member of the Education Committee of the International Test and Evaluation Association.

EDUCATION:

B.S., Aerospace Engineering, University of Cincinnati. 1968
M.S.. Aerospace Engineering, University of Tennessee, 1972
Ph.D.. Aerospace Engineering, University of Tennessee, 1975

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James D. Lang is the Director of Flight Technology Integration in the Boeing Company. Phantom Works organization. He is responsible for development of aerodynamics, propulsion, and integration technologies for air and space vehicles. His team has members in St. Louis, Missouri; Seattle, Washington; Long Beach, Huntington Beach. and Seal Beach. California

Jim is from Chicago, Illinois. He has a BS in Engineering from the US Military Academy, a MS in Aeronautics and Astronautics from Stanford University, and a Ph.D. in Aerodynamics from Cranfield University, England. He is a Fellow of the AIAA, a Fellow of the Royal Aeronautical Society, and a member of the USAF Scientific Advisory Board.

Jim retired as a Colonel from the US Air Force in 1987 with 24 ½ years experience as a Command Pilot and Engineering Manager. Air Force duties include responsibilities at the Aeronautical Systems Division Wright-Patterson AFB, Ohio, as Deputy Commander for Engineering, Director of the Avionics Laboratory. Chief of the Flight Control Division. and Deputy Director of Flight Test Engineering. He also served as Associate Professor of Aeronautics at the US Air Force Academy. He has over 3,000 flight hours. including 320 combat missions in Vietnam as a Forward Air Controller.

His other assignments at Boeing (formerly McDonnell Douglas) include, from 1992 to 1995. as Director of F-15 and F-4 Program Engineering. During 1990-1992. he was assigned as Director of Engineering and Deputy Program manger for the National Aero-Space Plane program. From 1988-1990, he was the Director of Flight Sciences Engineering and supported the F-15, F/A-18, AV-8B, T-45, A-12, YF-23, C-17, and MD-l 1 programs, and was responsible for technology development in the flight sciences.

Dr. John P. McCarty
McCarty Group. Inc.
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QUALIFICATIONS AND BACKGROUND:

John P. McCarty is President of McCarty Group, Inc., a firm organized to provide planning, research. development, and consulting expertise to aerospace and related industries, government and universities in the areas of propulsion and space transportation.

Until early 1996, Dr. McCarty was Director of the Propulsion Laboratory, Science and Engineering Directorate, Marshall Space Flight Center, National Aeronautics & Space Administration in Huntsville, Alabama. In this position he managed the propulsion engineering and test activities to support the broad range of propulsion projects at the Center in support the Nation's Space Program.

Dr. McCarty received a Bachelor of Science Degree in Mechanical Engineering from the Massachusetts Institute of Technology, a Master of Science Degree in Business from Stanford University. and Master of Science and Doctor of Philosophy Degrees in Engineering from the University of Alabama in Huntsville.

Dr. McCarty began his professional career in 1958 as a test engineer with Rocketdyne Division, Rockwell International. He moved to Chrysler Corporation, Space Division doing research and analysis of propulsion elements in 1960 and transferred to the Marshall Space Flight Center, National Aeronautics & Space Administration in March 1963 to conduct research and development of rocket engines and space transportation systems.

At MSFC, he served in progressively responsible positions from 1963 to 1974 within the former Propulsion and Vehicle Engineering and the Astronautics Laboratories. From 1974 to 1978 he was a Senior Project Engineer in the SSME Chief Engineer's Office, in 1978 he was named Technical Assistant to the Director, Science and Engineering Directorate and in 1982 he was named Chief of the Propulsion Division, Structures and Propulsion Laboratory. In 1985 he was named Deputy Director of the Structures and Propulsion Laboratory and in 1986 was made Director of the Propulsion Laboratory where he served until early 1996.

Dr. McCarty is nationally recognized for his expertise, serves as authority and consultant for propulsion system definition, design, development, and certification, and functions as a focal point for conceptualizing and structuring of new projects and activities or implementing special activities to resolve extraordinary needs or problems.

Dr. McCarty has received numerous awards including the Presidential Rank of Meritorious Executive. He is a Fellow of the American Institute of Aeronautics and Astronautics. and a member Tau Beta Pi Honorary Society.

Captain Joel J. Schubbe
Chief. Acoustics & Sonic Fatigue Branch
Structures Division, Air Vehicles Directorate
AFRL

Captain Joel J. Schubbe, Ph.D. was born in Iowa and raised in Northern Indiana. He earned his Bachelor of Science degree in Engineering Sciences-Structural Analysis and Materials and his commission in the U.S. Air Force from the U.S. Air Force Academy in Colorado Springs, Colorado in May 1986. Captain Schubbe served as an Armament Systems Analyst at the Air Force Foreign Technology Division, Wright-Patterson AFB. Ohio until entering the School of Engineering, Air Force Institute of Technology. in May 1989. He earned the degree of Master of Science in Aeronautical Engineering in December 1990 with thesis work in advanced metal matrix composites. Captain Schubbe then served as Aerospace Test Facilities Manager, supervising daily operations, repair, maintenance, and upgrades of the Propulsion Wind Tunnels and Von Karman Facility at Arnold AFB, Tennessee. He also managed weapon system test programs developing the F-22. F-18E/F, NASP, Navy Standard Missile, and others as a Program Test Manager for Aerospace Systems at Arnold until returning to the Air Force Institute of Technology in July 1994. Captain Schubbe completed his Ph.D. in 1997 with doctoral dissertation research in Aging Aircraft Bonded Composite Repair. He currently serves as the Chief. Acoustics and Sonic Fatigue Branch, Structures Division of the Air Vehicles Directorate in the Air Force Research Laboratory at Wright-Patterson AFB. OH.

Dr. Robert W. Selden
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EDUCATION:

University of Wisconsin
Ph.D., Physics, 1964
M.S., Physics, 1960
Pomona College
B.A., Physics, 1958

WORK EXPERIENCE:

Los Alamos National Laboratory. Los Alamos, NM
Associate Director for Laboratory Development, 1991-1993
United States Air Force, Washington, DC
Chief Scientist. 1988-1991
Los Alamos National Laboratory. Los Alamos, NM
Director, Center for National Security Studies, 1986-1988
Associate Director. Theoretical & Computational Physics, 19841986
Deputy Associate Director, Strategic Defense Research. 1983-1984
Division Leader, Applied Theoretical Physics, 1979-1983
Lawrence Livermore National Laboratory, Livermore, CA
Assistant Associate Director, Nuclear Design, 1978.1979
Group Leader, Nuclear Design, 1973-1978
Staff Member. Applied Physics, 1967-1973
United States Army
Research Associate, Lawrence Livermore National Laboratory, 1964-1967

AREAS OF EXPERTISE: Strategic planning for science and technology; research management; weapon systems: nuclear weapons; computational science; directed energy; explosives and propellants; avionics including architecture and integration; low observable technology.

Dr. Ralph Shimovetz
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Engineering Position In Acoustics and Vibration

SUMMARY OF QUALIFICATIONS:
Dec 65 - Present

Acoustics and Sonic Fatigue Branch
Wright Patterson AFB, Ohio
Aerospace Engineer working in the area of high level acoustics and vibration problems with aircraft structures combined with high temperatures. Areas included testing of structural components, electronic devices ,and whole missiles and substructures. Designs of test fixtures, test plans and test program management were performed. Theoretical estimates of acoustic levels and vibration response were performed from empirical methods. Managing contracts with airframe companies and research institutions for studies in acoustic prediction, and vibration methods applied to reduction in levels and of describing damage and strengthening structures.

Thirty-eight publications including 4 conference papers and 1 book chapter. Developed methods for combining 2, 3, and 4 noise modulators to function together and produce the theoretical sound power. Technical lead on upper wing structure damping program tc eliminate fatigue cracking on F 15 aircraft. Designed new facility components to develop 165 dB for cruise missile tests.
June 72 -April 75 Concurrently

EXPERIENCE:
ACUTEC INC
Dayton. Ohio
Consultant Engineer in industrial acoustics and vibration problems in manufacturing and chemical processing plants.

EDUCATION:
University of Dayton
Dayton, Ohio
Master of Mechanical Engineering -- April 1988
Bachelor of Mechanical Engineering -- Dec 1965

Accreditations:
Professional Engineer State of Ohio
Professional memberships
American Society of Mechanical Engineers
American Institute of Aeronautics and Astronautics
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Dr. Richard Thornton
President, MagneMotion, Inc.

EXPERIENCE: **46 years**
EDUCATION: B.S.. Electrical Engineering, Princeton University
S.M., Electrical Engineering, Massachusetts Institute of Technology
Sc.D., Electrical Engineering, Massachusetts Institute of Technology

Richard Thornton has been a Professor of Electrical Engineering and Computer Science at MIT for more than 40 years, with primary research in magnetic levitation and propulsion. Richard has 14 patents and has written more than 60 papers in the areas of maglev, linear motor and fault tolerant control, electronic circuits, and electromechanical systems. He was one of the founders of Thornton Associates, a successful commercial provider of precision instruments, and remains as its Chairman. He has a BS from Princeton and an MS and PhD from MIT. Richard is also a member of the Board of Directors of MagneMotion.

Summary: More than 40 years experience as Professor and researcher in areas of magnetic levitation, linear motor propulsion, electro-mechanical systems, electric cars, electronic circuits, semiconductor devices, and power electronics and control. Co-developer of MIT Magneplane maglev vehicle system.

Richard D. Thornton is a Professor of Electrical Engineermg and Computer Science at MIT with primary research in magnetic levitation and propulsion and power electronic control systems. In addition, he teaches and is involved in research on modeling and simulation of electronic circuits and microprocessor controlled electromagnetic and electromechanical systems. Starting in 1965 Dr. Thornton worked on various transportation projects in conjunction with the D.O.T. supported MIT Project Transport This work included electric propulsion systems for electric cars and linear motors.
From 1970 to 1975, Dr. Thornton worked with Dr. Henry Kolm and others at MIT on the development of the NSF supported MIT Magneplane. The magneplane was the first design to incorporate cryogenic magnets for levitation and propulsion with an active guideway Linear Synchronous Motor for propulsion and ride control. Dr. Thornton is author or co-author of 3 international patents on the Magneplane System. He was a member of the Maglev Technical Advisory Committee, reporting to the U. S. Senate Committee on Environment and Public Works, and is a co-author of two volumes written by this Committee; a published executive summary and a second volume for which he wrote the maglev technology section and co-authored the maglev vehicle section. Over the last 4 years he has given more than 30 talks to a variety of audiences on many aspects of maglev systems.

Since 1988 Dr. Thornton has been working on new ideas for maglev, linear motor propulsion and automated transportation systems. He has supervised doctoral theses on

magnetically levitated flywheels, linear synchronous motors, position sensing, and communication and control for transportation. Dr. Thornton also has considerable experience, and teaches graduate level courses, in the area of Electronic Circuits with particular emphasis on symbolic and numerical methods for modeling and simulation

He was a principal investigator of two BAA projects as part of the National Maglev Initiative. In this role he coordinated the work of 6 students and 4 other faculty. He was the principal author of the report on Linear Synchronous Motors and was a major contributor to the report on Low Cost Guideways. Since 1987 the main focus of Dr. Thornton's work has been on maglev suspension, linear motor propulsion and fault tolerant control. He has written several papers and presented many talks on the design of suspension systems and power electronic control systems.

Professor Rick I. Zadoks
The University of Texas – El Paso
Mechanical & Industrial Engineering

EDUCATION: BSME. Purdue University, December 1983
MSME, Purdue University, August 1985
PhD (ME), Purdue University, August 1988
(specializing in nonlinear vibrations)

PROFESSIONAL EXPERIENCE:

Assistant Professor, Mechanical Engineering, The University of New Mexico, Albuquerque, NNM, August 1988-August 1994

Associate Professor, Mechanical and Industrial Engineering,

The University of Texas at El Paso, El Paso, TX,
August 1994 - Present

Consultant. Los Alamos National Laboratory, Los Alamos, NM,
May - August, 1992

Consultant, Sandia National Laboratories. Albuquerque, NM,
May 1993 - September 1994

Professor Ben T. Zinn
Georgia Institute of Technology
School of Aerospace Engineering
David S. Lewis. Jr. Chair, Georgia Institute of Technology
Regents' Professor
Schools of Aerospace Engineering and Mechanical Engineering
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Atlanta, Georgia 30332-0150

EDUCATION:

BS Cum Laude in Mechanical Engineering, New York University, 1961
MS in Mechanical Engineering, Stanford University, 1962
MA in Aerospace Engineering and Me. Science, Princeton University. 1963
Ph.D. in Aeronautical Engineering and Mechanical Engineering, Princeton University, 1965

EXPERIENCE:

Dr. Zinn joined the Georgia Institute of Technology in 1965 after completing his Ph.D. studies at Princeton University. He attained the rank of Regents' Professor in 1973. His fields of research have included: Liquid and solid rocket combustion instabilities. ramjet and jet engine combustion instabilities, oscillatory flame phenomena, reacting flows, soot formation, acoustics of complex geometries, wave propagations in nozzles and pulse combustion. He has published 118 refereed papers. over 224 reports and unrefereed papers, edited two AIAA Progress Series books on combustion diagnostics. wrote a chapter entitled "Pulsating Combustion" which appears in *Advanced combustion Methods* published by Academic Press, and given over 365 seminars and lectures at various universities and conferences throughout the world. Finally, Dr. Zinn is co-holder of seven patents in the field of pulse combustion.

Dr. Zinn is active in the AIAA, The Combustion Institute and JANNAF. He has been an Associate Editor of the AIAA Journal, General Chairman of the 15th AIAA Aerospace Sciences Meeting and member of the AIAA Propellants and Combustion Technical Committee. He has held various positions on the board of directors of the Eastern Section of The Combustion Institute including its vice-chairmanship and chairmanship. Dr. Zinn served on various JANNAF, NIH, DoE and DoD committees, workshops and review panels and program committees for numerous conferences. He was a visiting professor at Stanford University and Northwestern Polytechnic Institute in Xian. The People's Republic of China. He was appointed by Commerce Secretary Juanita Krepps to the Board of Visitors of the National Academy for Fire Prevention Control.

Dr. Zinn served on the editorial boards of *Combustion Science and Technology, Fire Research,* and *Progress* in Energy *and Combustion.* He is a reviewer for several journal and a proposal reviewer for several government agencies. Dr. Zinn has received many honors including Fellow of the AIAA, Fellow of the ASME, NASA's Certificate of Recognition, and Georgia Tech's Sigma Xi Sustained Research Award. In April of 1990,

he was presented the “Distinguished Professor Award for 1990” at Georgia Tech and in June of 1991, The Honorary Professorship Award from the Beijing University of Aeronautics and Astronautics, Beijing, The People’s Republic of China. In 1992, he received the David S. Lewis, Jr. Chair award, and in January of 1995, he was elected a member to the National Academy of Engineering. He received the AIAA Propellants and Combustion Award for 1996 for “outstanding contributions to understanding of rocket instabilities and pulse combustion development and being among the first to realize its full potential in industrial processes,” and was recently honored at Georgia Tech for winning of the “1997 Faculty Research Award for Outstanding Achievement in Research Development.” Also, a number of Dr. Zinn’s students have won research awards for their research efforts.